CURRENT MEASURING DEVICES

No. 28FR

NATIONAL RADIO INSTITUTE
EST. 1914
WASHINGTON, D.C.

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NATIONAL RADIO INSTITUTE



WASHINGTON, D.C.

NCP1M62931

Printed in U.S.A.

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ELECTRICAL QUANTITIES

The knowledge of *how great* or *how small* a thing is, is of just as much importance in Radio as in any other phase of life. If you go to the carpenter and tell him to make a table for you, he will ask you how long you want it, how high it should be, how much weight it must be able to bear, and so on.

Immediately you think of a foot-rule, or a yard-stick, or some other length-measuring instrument with which you are familiar. You tell the carpenter that the table must be 6 feet long. You are unconsciously comparing the length which you desire the table to have with the length of a piece of wood you have at home, which you call a foot-rule. What you really mean when you tell the carpenter that the table is to be 6 feet long is that it should be six times as long as that particular piece of wood.

It is clear from this that all measurements are really *comparisons*. The thing which you wish to measure is compared with some other thing with which you are familiar. Everything has a certain property or characteristic which we call quantity. Length, weight, velocity, resistance, capacity, time, current, voltage, density—all these are quantities. All these are measured by comparing them with a certain standard which we call a *unit*.

The foot is a unit of length; the second is a unit of time; the pound is a unit of weight; the henry is a unit of inductance; the ohm is a unit of resistance, and so on almost indefinitely.

Sometimes we have several units. For example, the unit of length may be the *inch*, the *centimeter*, the *knot*, etc. But this all amounts to the same thing, because we know that there must be certain simple relations between these various units. The inch is equal to 2.54 centimeters; if we measure a length and find it to be 10 inches long, we know immediately that if we had used a centimeter scale instead of an inch scale, our measurement would have given us 25.4 centimeters as the length. In other words, the length may be considered as so many times any standard unit. If measurements are made by different persons using different systems of measurement, then the relation between the two systems must be known.

An English pound (speaking of money), in normal times,

has the same value as about five dollars in United States money. You may have *one* pound or *five* dollars; in either case your wealth would be the same, because you can buy the same amount of goods with either one pound or five dollars. You are *comparing* the two amounts of money with the same thing—that is, with the amount of goods which you can buy with either amount. Since you can buy the same amount of goods in either case, then the two amounts of money must be *equivalent,* or equal in value.

In other words, all measurements are *comparisons.* But some comparisons may be *direct* and some may be *indirect.* For example, by laying a foot-rule along a certain pencil line, we compare the length of line with the length of the rule. But we can't measure the speed of a train in any such way. First we have to measure a certain distance with our foot-rule, or by some other convenient means; then we have to cause our train to run over this distance, and measure the time it takes it to do so with a stop-watch. This is another comparison; we compare the time which the train takes with the time it takes the hand of the clock to travel around the face of the watch, or with the time the sun takes to travel completely around the earth, since there is a known relation between this time and the rate at which the clock hand moves.

Then, knowing the distance and the time, we simply say that the train has passed over so many miles in so many minutes, and we have the expression miles-per-minute. This is an indirect measurement, or comparison. We must measure two quantities in order to know the third.

For example, we have no such thing as an *ohm* which we can pick up and compare with the ohms in a piece of wire. As a matter of fact, we can't *handle* any of the electrical quantities, so that we cannot compare them directly. We can only measure them by *what they can do.* For example, we measure the amount of current flowing in a conductor by the amount of magnetic flux that this current can establish about the wire; we measure the magnetic flux by the amount of work it can do in lifting a given weight through a given distance, and so on. Most measurements that we make in radio are indirect measurements. We measure two or three quantities, each one by an indirect method, and then compute a third quantity by means of these indirect measurements.

It may seem quite strange, but it is a fact, nevertheless, that we do not measure current with an ammeter, nor do we

measure voltage with a voltmeter. All that we do is this: we construct a movable system working in a magnetic field and when we pass a current through the coil of this magnetic system it performs work; it acts upon the movable mechanical system and causes it to deflect an indicating needle. By a series of indirect measurements, the manufacturer of the meter has determined that when a certain current passes through the coil the needle will be deflected so far, and at that point on the scale of the meter he places a mark—1 volt, 2 volts, or 1 ampere, 2 amperes, and so on.

However, as far as the radio experimenter or service man is concerned, he need not be concerned greatly by all this. If he has come to realize that the measurements he is making are indirect—in other words, after he has clearly understood the meaning of the terms direct and indirect measurements—he may just as well regard the deflection of the meter needle as indicating so many volts or so many amperes.

In radio and electrical design, research, maintenance and servicing we definitely depend on our ability to measure electrical quantities in terms of:

Amperes	units of current
Volts	units of potential difference
Watts	units of power
Cycles	units of frequency
Ohms	units of resistance, reactance or impedance
Farads	units of capacity
Henries	units of inductance

The subject of radio measurements, contrary to general belief, includes, to a great extent, ordinary electrical measurements. All measurements are generally made by means of *visual* indicating apparatus and seldom, if ever, through our sense of smell, taste, feeling or hearing. But as the theory of design and operation of every type of electrical meter is an extremely vast and detailed subject, involving much higher mathematics, in our study of radio measurements we will adhere to a simple explanation of theory and operation, devoting our attention principally to the purpose and use of electrical testing devices and systems. It is important that Radio-Tricians be able to select the proper meters or current measuring arrangements to suit their needs. We are going to assume that your previous study of electricity and Radio has given you an understanding of the full significance of the ampere, volt, watt, cycle, ohm, farad and henry—common electrical units.

GALVANOMETERS (Tangent)

Electric current cannot be seen or heard, nor can we smell it. Yet the effects of electric current flow are very definite, and it is these effects that help us devise ways and means to measure it. As we study various instruments, these effects will be clear to us.

The galvanometer is the basis of all D.C. current meters. There are two classes of galvanometers, differing in their principle of operation. In the first a magnetized needle is caused to move when influenced by a magnetic field produced by a nearby coil of wire carrying the current to be measured. In the second, a coil of wire suitably located between a N and S pole of a permanent magnet or electromagnet deflects when the current to be measured is allowed to flow through the suspended coil.

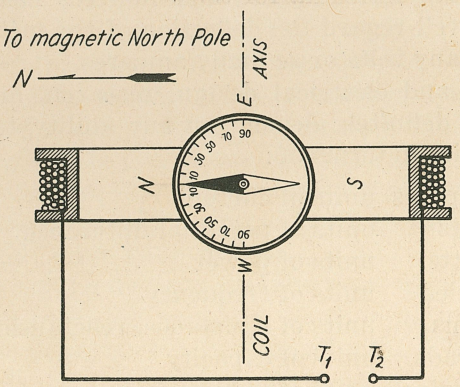


FIG. 1a

In either case the magnetic effects of electric current are made use of, and we might say that this effect forms the basis of most modern electrical instrument operation. Galvanometers of the magnetic needle type are practically never used for measuring purposes, yet a study of them is very instructive, as it will lead to an understanding of direct and indirect calibration of meters of all types. A simple galvanometer of this type, called a *tangent* galvanometer, may be easily built by the student. About 30 turns of double cotton covered wire, No. 24 B. & S. Gauge, are wound bank-fashion on a circular tube 4 inches in diameter and the wire concentrated in as narrow a space as possible. In the center, a free-moving pivoted compass, calibrated in degrees, is placed exactly as shown in Fig. 1a; that is, the pivot axis of the compass is perpendicular to the axis of the

coil. The coil of wire is placed in the circuit whose current is to be measured.

The entire tangent galvanometer is set up so that the compass needle is free to move and the instrument turned so that the needle will always point north and south with respect to the earth's magnetic pole—the earth's field is perpendicular to the coil's axis. In Fig. 1a, the needle points to zero. Now when a current is sent through the coil, two forces act on the needle as shown in Fig. 1c; the magnetic force H of the earth's magnetic field, and a force to the right or left depending on the direction of current in the coil and equal to $\frac{2\pi NI}{r}$, where N is the number of turns in the coil, I is the current in amperes, and r is the radius of the coil in inches. From simple trigonometry* we may now have a formula for the current:

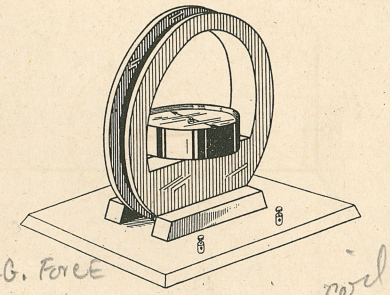


FIG. 1b

$$I = \frac{H \times r}{N} \times \text{tangent } \theta \quad (1)$$

The needle of the compass will be drawn away from its normal position—toward the earth's north magnetic pole—by a certain number of degrees, depending on the amount of current flowing through the coil. The angle it makes with the normal position is considered "θ," the Greek letter "theta." To obtain the tangent of any angle we refer to a table of tangents. Then, knowing the degrees of deflection, we can easily find the tangent θ for use in formula No. 1. "H" varies with various localities. For Washington it is .81; for Boston .70; for Chicago .76; for New York .75; for San Francisco 1.02. Now we have enough information to calculate the current in amperes.

* The branch of mathematics that deals with the measurements of the sides and angles of triangles.

Example: In Washington, using a 30 turn coil on a 4 inch form, let us say the compass needle is attracted 30 degrees away from N. What current flows through the galvanometer? (Tan 30° = .58.) From formula (1):

$$I = \frac{.81 \times 2 \times .58}{30} = .031 \text{ ampere} = 31 \text{ milliamperes.}$$

What would be the current if the coil had 100 turns and the deflection angle was still 30 degrees?

$$I = \frac{.81 \times 2 \times .58}{100} = .0094 \text{ ampere} = 9.4 \text{ milliamperes.}$$

The two examples show that a tangent galvanometer having many turns can be used to measure weak currents. Close examination of equation (1) reveals that for any particular galvanometer of this type the current I is always found by reading the

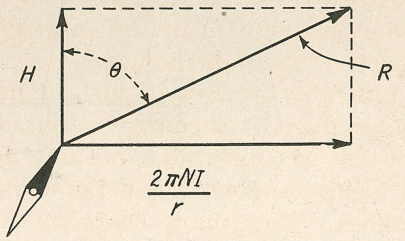


FIG. 1c

angle θ, and multiplying its tangent by a constant equal to $\frac{H \times r}{N}$. This should be clear when we realize that, for any locality, H does not change, and the radius and the number of turns are always fixed once the instrument is built. For simplicity we say that $\frac{H \times r}{N} = K$; that is, some number which is always the same as long as H, r and N are not altered. Bearing in mind that K is nothing more or less than $\frac{H \times r}{N}$, formula (1) may be written as:

$$I = K \times \tan \theta \qquad (2)$$

For the 30 turn galvanometer, $K = \frac{.81 \times 2}{30} = .054$; for the 100 turn coil $K = \frac{.81 \times 2}{100} = .016$. Now we have made possible the

use of the our galvanometer for more direct measuring purposes.

$$\text{For the 30 turn coil } I = .054 \times \tan \theta \qquad (2a)$$

$$\text{For the 100 turn coil } I = .016 \times \tan \theta \qquad (2b)$$

If you want to, you can substitute tan 30° in (2a) and (2b) and you will get the same answer that we obtained from formula (1). Note how simple the equation becomes once K is known. Let us say we don't know a thing about trigonometry, but we know enough to read a tangent table; that is, a table in one column of which are given degrees of angles, and, in the other, this something called the tangent θ. The tangent galvanometer coil is connected in the circuit to be measured, and before the current is allowed to pass through the coil the compass needle is made to point to zero. The shunting switch (all sensitive meters should be shunted by a short circuiting switch) is opened and the angle of needle deflection read. The angle will always be less than 90°. Tan θ is obtained from the table and multiplied in one case by .054 and in the other by .016 for the current in amperes.

K is the constant of the galvanometer (the meter constant), and a meter constant plays a very important part in all electrical and radio measurements. It changes a quantity like "tan θ" into amperes. The use of constants is nothing new to you. How many inches in 4 feet? Anyone would immediately multiply by 12 and say 48 inches. How many cents in 4½ dollars? One hundred times, of course. These are constants because there are *always* 12 inches in one foot, *always* 100 cents in each dollar.

But suppose we don't know the value of H. We may live in a locality for which the value of H has not been worked out. Then we can't calculate the value of K to be used in connection with our tangent galvanometer. But still we want to use our tangent galvanometer to measure current.

The only thing to do is work out the value of K backwards, as it were. To do this we must know how much current is flowing for a certain deflection of the compass needle.

Naturally we shall have to use a standard calibrated current meter. Let us assume that as in Fig. 2, a standard meter is in series with our tangent galvanometer, a rheostat and a source of e.m.f., so that a variable current can be made to flow through the standard and the secondary instrument (the tangent galvanometer). The rheostat is adjusted for a convenient deflection of both the meter needle and the compass needle and the readings of each are noted. Suppose the tangent galvanometer reads

30° and the standard current meter reads 31 milliamperes (.031 amp.). Knowing this, we can calculate the galvanometer constant from equation (2):

$$I = K \times \tan\theta$$
$$.031 = K \times \tan 30$$
$$.031 = K \times .58$$
$$K = \frac{.031}{.58}$$
$$K = .054$$

Thus by the use of a standard meter and simple mathematics we have derived the value of K. Having calculated the value of K for our particular instrument and locality, we can calculate current values for various deflections of the compass needle.

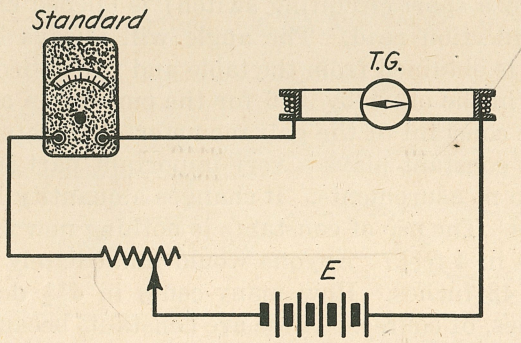


FIG. 2

As a point of interest it should be mentioned that, knowing K, we can derive the value of H for any locality because $K = \frac{H \times r}{N}$, and we know r and N. Knowing the value of K, we can easily solve for H.

Measurements of current made by using formulas (1) and (2) are only approximate, as there are many factors which must be considered if we want our results to be exact. For example, formula (1) is strictly true only if the coil of the tangent galvanometer is perfectly circular; if it has only one concentrated layer; if the needle of the compass is in the exact center and is extremely small; if it is perfectly balanced; if there is no friction at the pivot; if the coil is properly placed with respect to the magnet and the earth's magnetic field; and if there is no iron or steel in the vicinity to affect the compass reading. However,

if we calibrate the instrument by comparing it to a standard meter, many of these factors may be neglected.

How can we calibrate our tangent galvanometer so that it won't be necessary to calculate current values mathematically? We would use the same set-up shown in Fig. 2. At various values of current (various adjustments of the rheostat) we would record the standard meter reading and the compass needle reading. Let us say we set the rheostat at various positions for a compass needle reading of 10, 20, 30, 40 to 90 degrees. At each position we will read the value of current flowing (the standard meter reading). We might get something like this:

T. G. θ	Standard
10°	.0018 amp.
20°	.0058 amp.
30°	.0092 amp.
40°	.0136 amp.
50°	.0190 amp.
60°	.0277 amp.
70°	.0440 amp.
80°	.1000 amp.

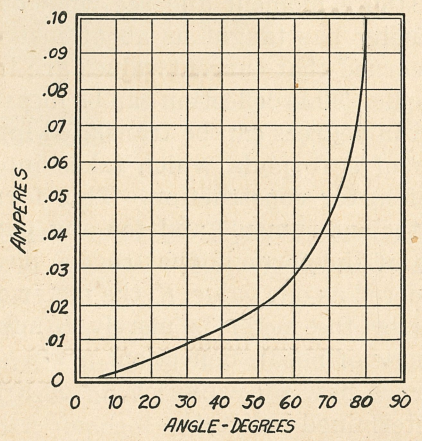


FIG. 3

From these recorded readings we can plot a calibration curve as shown in Fig. 3. Then for any reading of the tangent galvanometer we can refer to the calibration curve and obtain the value of current flow in amperes.

We can go even a step farther than this and make of our

tangent galvanometer a direct reading device. From Fig. 3 we can derive the following table:

I	θ
.0025 amp.	13°
.005 amp.	22°
.01 amp.	33°
.02 amp.	53°
.03 amp.	62°
.04 amp.	69°
.05 amp.	74°
.06 amp.	77°

Removing the original 0 to 90 degree scale of the compass, we put in its place a special scale marked in accordance with the table given above. That is, at the 13° position we mark and write in .0025; at the 22° position we mark and write in .005; at the 33° position we mark and write in .01 and so forth, up to .1. Then each of these main divisions can be divided into ten equal parts, each subdivision representing .001 amp.

With the tangent galvanometer calibrated in this manner, no tables, calculations or calibration curves are needed. The amount of current flowing can be read directly.

Now let us stop a moment and see what our study of the tangent galvanometer has taught us about instruments in general. We have learned that current values are indicated by the deflection of a needle. This deflection can be measured in degrees and the deflection in degrees can be translated into terms of amperes by the use of a formula which takes into consideration all the factors of meter construction. This formula expresses the behavior of the instrument, and for any particular instrument the portion of the formula that covers physical construction can be considered as one value, K, the meter constant. Then the current read by the meter is merely K multiplied by the tangent of the angle of needle deflection.

We also learned how the value of K for a finished instrument could be determined indirectly.

Then we learned how a calibration curve could be made so that separate calculations for each reading would not have to be made. We also saw how the instrument could be made into a direct reading device.

Thus we have learned a great deal about instruments in general, for practically all measuring instruments indicate values by needle deflection over a certain number of degrees. Every

instrument has its meter constant by which the degrees of deflection can be changed to electrical quantities. And all commercial measuring devices are calibrated by comparison with a standard calibrated measuring device.

THE D'ARSONVAL GALVANOMETER

The D'Arsonval galvanometer is by far the most important current measuring device. In this type of instrument we have, not a magnetized needle, but a moving coil suspended in a permanent magnetic field, with the indicating device attached to the coil, as in Fig. 4. The coil is small, very light in weight, and rectangular in shape. It consists of a number of turns of very fine wire, and the entire coil is suspended on a thin flat phosphor-bronze wire. The suspension is such that the coil can rotate at

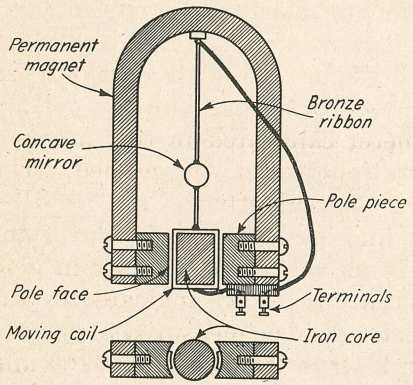
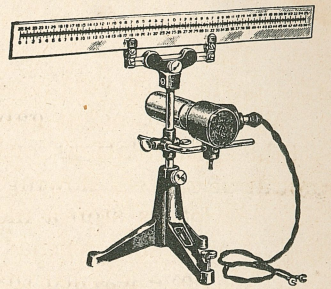


Fig. 4



Scale and lamp for semi-portable galvanometer

right angles to the magnetic lines of force from one pole face to the other. A concave reflecting mirror is attached to the suspension wire.

The current to be measured is made to flow through the coil. Then the magnetic field set up about the coil reacts with the permanent magnetic field, forcing the coil to rotate in one direction or the other, depending on the direction of current. The tendency of the coil to rotate is opposed by a counter-twist of the flat suspension ribbon. Therefore, the coil will turn until the torque (twisting force) due to the current is equal to the counter-torque of the suspension. At this point the indicating device will remain fixed, and if we know the "meter constant" and the amount of angular deflection, we can calculate the amount of current flowing.

In other words, we can calculate current from the formula $I = K \times \theta$ (where K is the galvanometer constant and θ is the angle of rotation in degrees).

Of course it isn't difficult to realize that a meter of this type can be made extremely sensitive, by using a very strong magnetic field, a large coil, a large number of turns and a weak repelling force in the galvanometer suspension.

The sensitivity of this type of galvanometer can be greatly increased by a special method of magnifying the movement of the indicating device. The method is shown in Fig. 5—there is a long-filament lamp in front of the concave mirror of the galvanometer so that light reflected from the mirror will be thrown on a frosted semi-transparent circular scale. Then the least rotation of the galvanometer will show up on the enlarged scale.

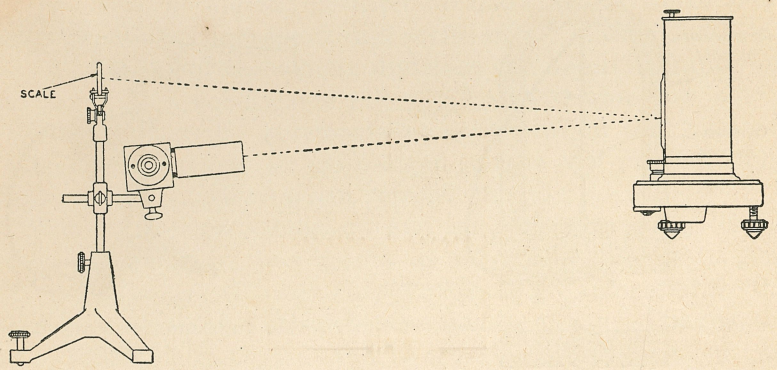


FIG. 5

The scales may be laid off in any convenient manner and each unit divided into ten equal parts. With this arrangement we still must use the formula just mentioned, but instead of measuring the angle, we note the number of divisions included in the deflection D, and the current formula can be restated thus:

$$I = K \times D \qquad (3)$$

You will note that in equations (1), (2) and (3) the letter K was used. It must not be inferred from this, however, that K is the same for all galvanometers—it represents the meter constant of a particular meter, its value depending on the construction of the instrument.

Now let us see how a device of this sort can be calibrated. First we have to find the value of K. Let us assume that there

are 40 equal divisions on the scale, one centimeter apart, and that each division consists of 10 parts. Zero will be in the center of the scale and there will be 20 large divisions on either side of the zero mark. Now we move the scale to the right or left until the image of the lighted filament is exactly in the center—at zero. Then we cause a current, the value of which is known, to flow through the galvanometer. Suppose the galvanometer is rated so that 10 microamperes (10/1,000,000 of an ampere) will cause the indicator to deflect to the end of the scale.

Now we want to get 5 microamperes so that we can get a needle deflection halfway across the scale for purposes of calibration. Let us assume that the meter has a resistance of 2,000 ohms. To get 5 microamperes through this meter we must have a voltage of $.000005 \times 2{,}000 = .01$ volt ($E = I \times R$). The question now is: How can we get .01 volt? By using a voltage divider across a source of D.C., as in Fig. 6.

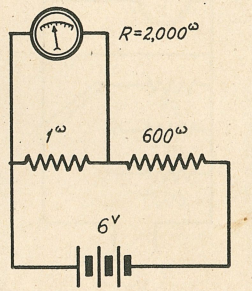


FIG. 6

A precision 1 ohm resistor is connected in series with a precision 600ω resistor, and both are connected across a fully charged 6 volt storage battery. If the battery voltage is higher than 6v, this is reduced to exactly 6v by a series rheostat. Of course a standard voltmeter must be used across the battery.

Then the current through the calibrating circuit is $6 \div 601$ or .00998 amp., and for approximate calculation we can consider this .01 amp.

Now if the voltage across the 1 ohm resistor is $1 \times .01$ or .01 volt, the current through the galvanometer is found from Ohm's law:

$$I = \frac{.01}{2{,}000} = .000005 \text{ amp.} = 5 \text{ microamperes,}$$

which is what we need. This current of 5 microamperes causes the galvanometer to deflect 9.5 divisions.

Then by substituting in formula (3) and finding the value of K for this particular galvanometer we get:

$$5 = K \times 9.5$$
$$K = .527$$

and knowing K we can calculate I for any other deflection of the indicating device. We would merely use the formula:

$$I = .527 \times D$$

Note that we substituted 5 microamperes in equation (3) instead of .000005 amp. to avoid the use of long decimals. Therefore, in the last formula, "I" will be in microamperes.

By placing a variable 2,000 ohm resistor in series with the galvanometer and adjusting it so that a deflection equal to 5 will

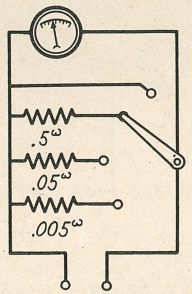


FIG. 7

represent 5 microamperes, we can read our scale directly in microamperes, for K in this case would be 1. Then from equation (3) we would find that:

$$I = 1 \times D \text{ or } I = D$$

That is, a reading of 2 would mean 2 microamperes, and a deflection of 7.95, if readings as close as this can be taken, would mean 7.95 microamperes.

From all that has been said about this meter, you can see very well that it is a microampere meter—that is, a microammeter. It differs from the ordinary ammeter of the type you carry in your tool kit only in construction; the underlying principle is the same.

A microammeter can be made to read large values of current by means of shunts. Still assuming that a deflection of

10 means 10 microamperes, if we used a 1 ohm shunt, a deflection of 10 would signify .02 amp.* and K would be .002 for the combination of galvanometer and shunt. The use of a .5 ohm shunt would make K equal to .001 and a deflection of 10 would mean .01 amp. With a .05 ohm shunt used, K would be .1, and with a .005 ohm shunt, K would be 1.

Knowing this, we can make of our microammeter a multi-reading ammeter by arranging it as in Fig. 7. A shorting contact connected across the galvanometer should be used to short the galvanometer when not in use. The use of shunts need not disturb the calibration of the instrument as long as they are small in comparison to the resistance of the galvanometer. However, when a shunt resistance is high, correction is essential.

D. C. AMMETERS AND MILLIAMMETERS

The D'Arsonval calibrated galvanometer principle was used by Edward Weston in 1888 in the development of what might

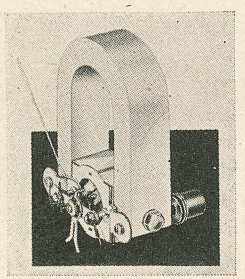


FIG. 8a



FIG. 8b

be considered the first practical, modern portable galvanometer. Details of the construction of the Weston galvanometer are shown in Figs. 8a and 8b.

There is a small, compact but powerful permanent magnet, with soft steel pole pieces and a soft steel core. The pole pieces are bolted to the permanent magnet and to a non-magnetic support.

The coil is wound of many turns of silk-covered, fine aluminum wire on a non-magnetic metallic frame. The coil is mounted in a pivot arrangement. There is a pivot point at each end of the coil exactly in the center of the core and the pivots themselves are set in polished, hard steel pivot holes, arranged di-

* Calculation of shunts will be taken up in a later chapter.

rectly above and below the exact center of the core. In modern high grade meters, jewel pivot sockets are used.

To the coil is attached a long needle which swings over an indicating scale. It is conventional for zero on this scale to be at the extreme left and maximum deflection to the right. In some cases zero is in the center of the scale and the indicating needle swings either to the right or left, depending on the direction of the current through the meter.

The air gap in which the coil rotates is made as small as possible so that the magnetic field through it will be strong. It is important that the distribution of flux in the area through which the coil moves be uniform and that the coil be not allowed to swing beyond the point of uniform field, or beyond the curvature in the pole pieces. A coiled ribbon spring is connected to the pivot and anchored to an arm which is a part of the end piece holding the bearing. The arm is adjustable so that the

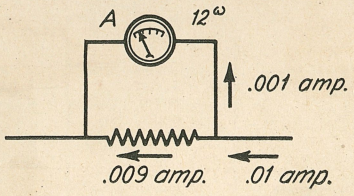


FIG. 9

tension of its spring can be changed. The needle is adjusted for zero in the same way. A spring coil is also used on the lower pivot, both springs being of phosphor-bronze. They provide the electrical connection to the coil windings provided the springs are led to insulated terminals.

A current flowing through the coil sets up a magnetic field which reacts with the permanent field, forcing the coil to rotate until the twist is balanced by the tension of the coil spring. The amount of current flowing can be calculated from the same formula we used with the D'Arsonval galvanometer ($I = K \times D$).

All that was said about calibrating the galvanometer applies also to the Weston type of instrument in every respect. The instrument we have been talking about is a milliammeter—that is, it indicates values of currents in thousandths of amperes. The milliammeter is the basic current measuring device.

For our study of the calibration of Weston type galvanometers, let us use a typical milliammeter. It will have a range

of from 0 to 1 milliampere and its coil will have a resistance of 12 ohms. The scale is divided into 10 divisions, and each of these is divided into 10 smaller divisions. Each small division represents 10 microamperes and each large division .1 milliampere or "mil." As there are 100 divisions on the scale and as these hundred are designed to represent 1 mil., K will be in this case $1 \div 100$ or .01.

By the use of shunts of various values, this basic milliammeter can be used to read from 0–10 ma., 0–20 ma., 0–100 ma., etc. The shunt to be used can always be calculated from Ohm's law. For example, suppose we want to use a 0–1 milliammeter to read from 0 to 10 ma. You remember the coil of the instrument has a resistance of 12 ohms. Then we must use that value of shunt resistance which, in parallel with these 12 ohms, will allow only .001 ampere to flow through the instrument and

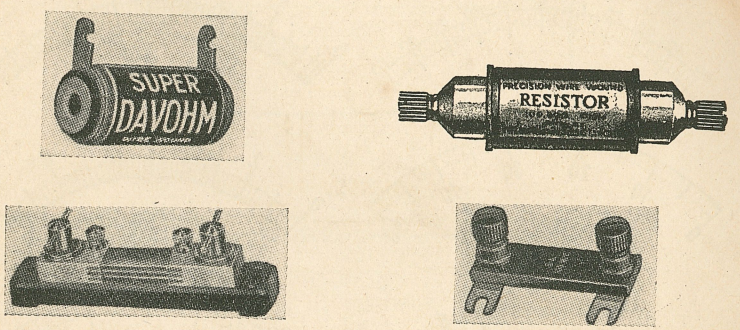


FIG. 10

.009 amp. through the shunt. Then with 1 milliampere through the instrument, 10 mils. of current through the circuit is indicated and full scale deflection indicates, not 1 mil. but 10 mils. as in Fig. 9.

The voltage drop across the milliammeter is $12 \times .001$ or .012 volt. The same voltage exists across the shunt. The resistance of the shunt must be such that, with that voltage across it, only .009 amp. will flow. The value of this resistance, from Ohm's law, is:

$$R = \frac{E}{I} = \frac{.012}{.009} = 1.33 \text{ ohms.}$$

Suppose we wanted to adapt our meter to read from 0 to 20 ma. Of course, full scale deflection will mean that 1 ma. flows through the meter and 19 through the shunt—and the total cur-

rent measured will be 20 ma. Again the voltage across both meter and shunt is .012 volt. The resistance of the shunt required is equal to $\frac{.012}{.019}$ =.63 ohm. For a 0–100 mil. range R will have to be $\frac{.012}{.099}$ = .121 ohm. Shunts for other ranges can be calculated in the same manner.

Typical shunts are shown in Fig. 10.

MISCELLANEOUS NOTES ON AMMETERS

An ammeter differs from a galvanometer in that it indicates current flowing directly in amperes, milliamperes or microamperes. The galvanometer also indicates current flowing, but the value of the current flowing must either be calculated or obtained from the calibration curve of the instrument.

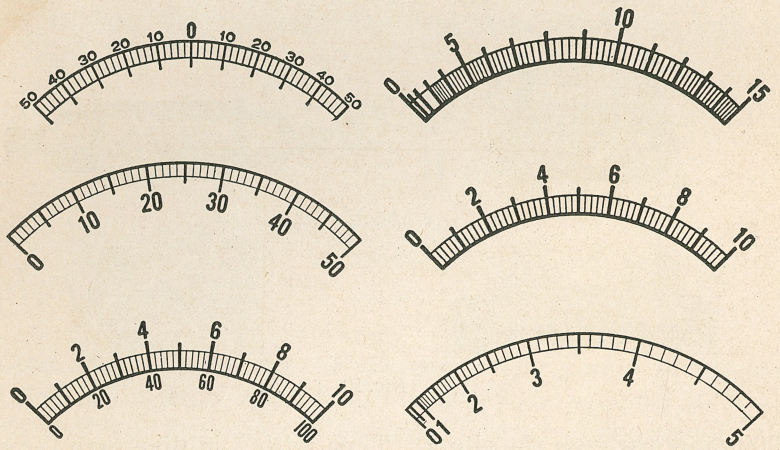


FIG. 11

The resistance of an ammeter should be very low in comparison with the resistance of the circuit in which it is connected. An ammeter having 15 ohms of resistance may be perfectly all right for measuring the plate current of a '45 tube which has a resistance of 1,900 ohms, as its insertion will not affect the value of current. But 15 ohms is hardly low enough when measuring the current in the UX-230 filament circuit—the resistance of the meter will affect the true current in the filament circuit.

A good ammeter is both rugged and reliable. The magnets are made as permanent as possible—they should not become weak with old age. Ammeter readings should be independent of stray magnetic fields, as in the case of the Weston type ammeter. The ammeter must be "dead beat"; that is, when a reading is taken the needle should swing up to the proper position and come to rest without swinging back and forth. This is accomplished by winding the coil on an aluminum frame so that the eddy currents, due to vibration and movement through the magnetic field, will impede any tendency to oscillate to and fro. Damping vanes should be used.

Scale graduations should be convenient. The 0 — 10 scale, with 5 or 10 subdivisions, is ideal. However, it is not always practicable, and individual scales, designed for various purposes, show marked differences. Several good scales are shown in Fig. 11.

THERMOAMMETERS

The hot wire ammeter is used extensively for making radio frequency measurements. While it can be used for measuring D.C. or A.C. of any frequency, it is not commonly used for anything but radio frequency work and, even then, only if there is considerable power. Its use is limited because of the large power required, because of its sluggish action and because it is often difficult to get the needle to return to zero. In addition to this, a slight overload is very apt to burn out a meter of this type.

Figs. 12a and 12b show the working principles of the hot wire ammeter. There is an alloy wire of platinum and silver, or platinum and iridium, stretched between A and B in Fig. 12a. The tension on the wire may be increased or de-

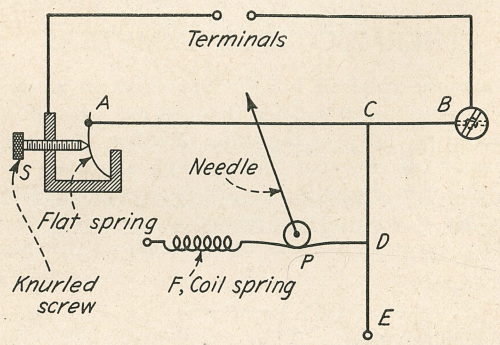


FIG. 12a

creased by adjustment of the set screw S. Between C and E there is a phosphor-bronze ribbon. From point D on this ribbon, around a cylinder to a coil spring F, is wound a silk cord. When a current is passed through wire AB, an I^2R loss takes place and the wire becomes hot. Naturally the wire expands and sags. The sag is transmitted to FP through the action of the spring, causing the cylinder P to rotate. An indicating needle attached to P moves over a convenient scale.

The active element of a hot wire ammeter is merely a single wire. Inductance and capacity are kept down to a minimum. The instrument is suitable for R.F. measurements as I^2R losses are independent of frequency. Hot wire ammeters for radio work (see Fig. 12b) are available that will read 100 ma., 250 ma., ½, 1, 3, 5 and 10 amperes. The meter resistances for these meters are 23, 8.5, 2.5, 0.9, 0.25, 0.07, and 0.052 ohm.

Let us consider for a moment the 1 ampere meter having 0.9 ohm resistance. The power to give full scale deflection is 9/10 of a watt, sufficient to introduce a considerable error into the reading. In some radio circuits the meter would constitute a load in itself. Nevertheless, it is used extensively, but with considerable caution.

In most cases a hot wire ammeter may be calibrated against a D.C. ammeter. The knurled knob is used for zero adjustment.

You will note from Fig. 12b that approximately 20 per cent of all the possible readings are lumped at the low end of the dial. This disadvantage however, is not confined to the hot wire ammeter but is also common to instruments of other types. Thus, in the case of the 100 ma. hot wire ammeter, readings below 20 ma. cannot be made very accurately.

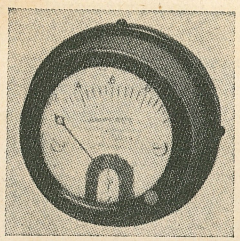


FIG. 12b

THERMOCOUPLE AMMETERS

For the reasons just explained, hot wire ammeters are not practicable for the measurement of currents much smaller than 20 ma. But R.F. currents that have to be measured are often of the order of a few microamperes. It is for measuring these small currents that thermocouple ammeters are used.

It is known that two dissimilar metals, like copper and iron for example, when joined together at one end and heated at the joint will produce a D.C. voltage across the open ends. This is the principle used in thermocouple ammeters. The current to be measured causes a joint between two dissimilar metals to heat up, and a voltage appears across the ends of these metals which can be measured. Thus by indirect methods we can measure very small values of current.

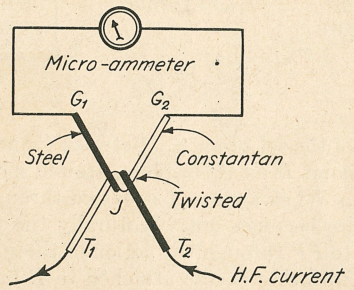


FIG. 13a

(Note. The H.F. current does not flow through meter)

Fig. 13 shows the working principle of a thermocouple ammeter. Two short, fine pieces of wire, one steel and the other constantan, are twisted together as shown. High frequency current is led to the terminals T_1 and T_2. The resistance of T_2JT_1 is perhaps 1 or 2 ohms and heats up due to the I^2R loss in it. The heat

developed is concentrated at point J. Wires G_2J and G_1J act as a thermocouple with J as the heated point.

In one type of thermocouple, a 10 ma. flow of high frequency current from T_2 to T_1 results in a 40 microampere current through G_2 and G_1. A D'Arsonval galvanometer can be placed across the D.C. output terminals or a portable microammeter can be used as in Fig. 13b. This particular galvanometer or microammeter has a 0—50 microampere scale and a D.C. resistance of 100 ohms.

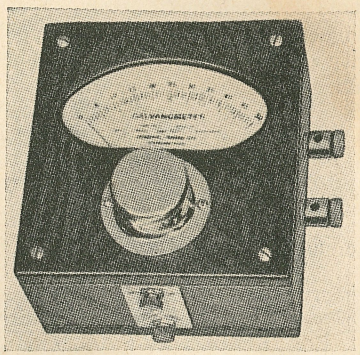
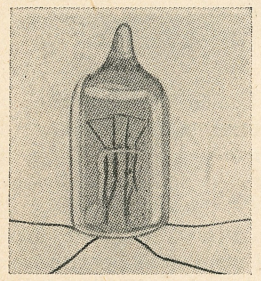


FIG. 13b

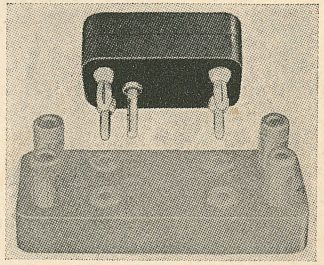
In other cases, 0—10 and 0—150 microampere scales can be used. Thus the instrument is excellent for the measurement of very small high frequency currents.

This instrument may be used for measuring all types of current—D.C. or A.C.—of any frequency, because no matter what type of current is used there is an I^2R loss. However, the real value of the thermocouple ammeter is for audio and radio frequency measurements. Due to the low capacity, inductance and resistance of the device, wide variations in frequency will not introduce much error into the readings.



COURTESY GENERAL RADIO CO.

Vacuum Thermocouple Element



COURTESY GENERAL RADIO CO.

Typical Mounting Case for Oxide Rectifiers and Thermocouples

Known values of D.C. current can be used for calibration purposes and a calibration curve obtained. For exact measurements it is best to reverse the current flow at each reading and take the average value for calibration purposes.

Often the milliammeter and thermocouple are built into one instrument, but the most sensitive instruments have the meter and the thermocouple separate.

MAGNETIC VANE AMMETERS (A.C. Measurements)

Commercial A.C. ammeters such as are used in all portable set analyzers are universally of the magnetic vane type.

Suppose a solenoid is fed with D.C. current. If a soft, annealed iron plunger is placed near an open end, it will be sucked in, even against the action of a spring which may tend to pull it out. The greater the current in the solenoid, the greater the pull. What happens is that the plunger becomes a magnet under the influence of the solenoid electromagnetic action. Now, if the D.C. current is reversed, the sucking-in action will continue. The polarity of the plunger reverses with the polarity of the solenoid. So, by using A.C. in the solenoid wires, the action of pulling in the plunger continues in spite of the reversal. However, there is a limit to the frequency at which this action occurs, and magnetic vane ammeters which employ this principle are usually limited to frequencies below 130 cycles.

Some of the inexpensive meters—D.C. as well as A.C.—use the principle illustrated in Fig. 14a. From our previous explanation, no trouble should be experienced in understanding how this simple ammeter acts. A scale is attached

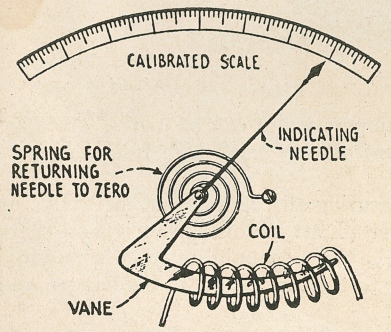


Fig. 14a

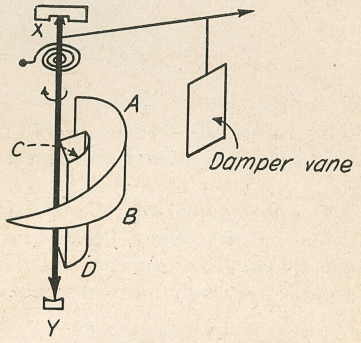


Fig. 14b

to the instrument, and by comparing to various known values of D.C. current, first in one direction then in the other, the instrument may be calibrated. The coil should be shielded from heavy fields of dynamo-electric machinery, dynamic speaker fields and power choke coils, and this shield is provided by the meter manufacturer.

The true magnetic vane instrument invented by Weston is shown in Fig. 14b. A thin piece of soft iron, *AB*, of triangular shape, is bent to cylindrical form, and placed firmly within a solenoid. Another piece of thin iron, *CD*, rectangular in shape but bent into a slightly smaller cylinder, is centered within *AB* being coaxial, that is, having the same axis *XY*. The latter is rigidly attached to *XY*, which has a pointer attached and a restoring spring. A direct current flows through the solenoid and both pieces of iron become magnetized. Edges *A* and *C* are of the same polarity and edges *D* and *B* are alike in polarity. Naturally they repel, and the only motion possible is in the direction of the arrow. The greater the swing the less the repulsion between *C* and *A*, as the edges become farther apart. It will take a greater flux strength and more current in the solenoid to force a greater rotation. The twist continues until balanced by the restoring spring. Fig. 14c shows the internal construction of an actual meter.

Rigidly affixed to the needle is a flat rectangular aluminum vane which rotates in, but without touching, an air-tight box. This air friction damper keeps the needle steady, on much the same principle as a tight rope walker uses a large fan or umbrella to steady himself. As the current rises, falls and reverses, the damper keeps the needle pointing to the r.m.s. value of current. Ordinarily magnetic ammeters have the readings bunched around zero and spread out at maximum, but much can be done by careful design of the shape and position of the repelling vanes to even out the scale. All good meters have hand-drawn calibrated scales reading correctly to ¼ to 2 per cent. Incidentally, the more precise, the more costly is the instrument.

The solenoid is strictly an inductance, and the use of shunts for A.C. work introduces considerable error into the reading. Service men should not use this type of instrument for D.C. when a D'Arsonval meter is at hand or without knowing that the instrument has been designed for both A.C. and D.C. measurements. Where an accurate ammeter of this type is designed for 2 or more readings, let us say, 1, 5, and 15 amperes r.m.s., a step-down transformer is usually built into the instrument; that is, a 15 to 1 and a 5 to 1. A typical one ampere

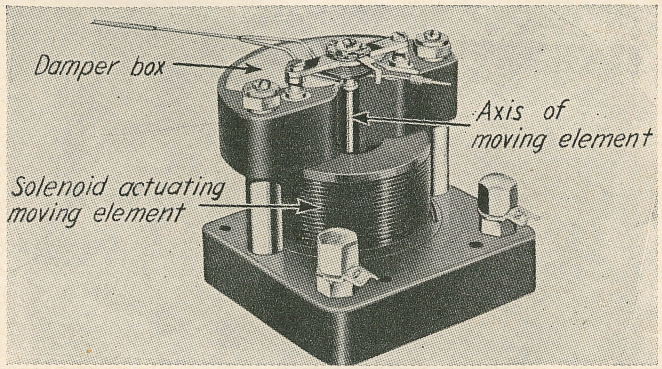


Fig. 14c

moving vane meter has an inductance of .1 millihenry and a resistance of 1 ohm; a 10 ampere meter an inductance of .85 millihenry and a resistance of .015 ohm. A 1 ampere meter will waste about 1 watt of power. It is well to bear in mind that magnetic vane ammeters are built for a maximum frequency and usually only for commercial frequencies of 60 cycles. A meter designed for 60 cycles may be safely used with frequencies up to 133 cycles per second.

ELECTRODYNAMOMETER A.C. AMMETERS

Although the electrician and radiotrician will always use the magnetic vane type of instrument for commercial frequencies, at times an electrodynamometer ammeter may be of advantage. Wattmeters operate on this principle as well as the better grade of meters used for direct measuring of capacity and inductance. This type of ammeter may be calibrated directly from its physical characteristics and so is an absolute measuring device, as compared to a secondary device. For example, the tangent galvanometer is an absolute measuring device, as the current can be determined by measuring the magnetic field and the size of the coil. The magnetic vane ammeter is a secondary device,

as it must be calibrated by comparing it to an absolute or standard. Practically every commercial instrument used in daily work is a secondary meter.

The coil *A*, in Fig. 15 which may be either circular or rectangular, is fixed. Within it is a similar coil, smaller, of course, so that it may rotate without touching, but yet quite close. Both coils are in series. When a current flows through coil *A*, a magnetic field is set up; the same current flowing through coil *B*, whose magnetic field is in the opposite direction, causes the movable coil to swing away. The larger the current, the greater the repulsion and the more the turning torque. Naturally the pointer moves until the magnetic twist is balanced by the back torque of the spiral springs. A damping vane, enclosed in a damper box, prevents the pointer from vibrating to and fro when a measurement is made.

When an A.C. current flows the magnetic field will first be in one direction and then in the other. But the coils are in series, and the same current flows through each and repulsion always exists. Consequently, the turning torque is always in the same direction. Electrodynamometer ammeters *always* read r.m.s. values. Like the magnetic vane ammeter, they are only for commercial frequencies of 0—133 cycles and almost always are calibrated for 60 cycles per

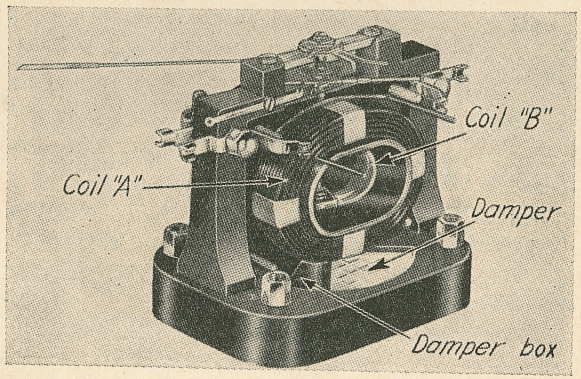


Fig. 15

second.* They must also be shielded from outside magnetic fields and be kept away from large steel construction work.

No iron is used in the moving system, consequently no magnetic hysteresis or eddy current losses take place. No magnetization of iron is necessary and very sensitive ammeters may be built. One manufacturer will supply electrodynamometer ammeters from 15 milliamperes to 10 amperes in semi-precision models. A 1 ampere model may have a resistance of ½ ohm and a 15 ma. meter a resistance of 1400 ohms.

OXIDE RECTIFIER AMMETER

Where A.C. current is to be measured, sensitive D.C. milliammeters may be used in conjunction with rectifiers. The use of the vacuum tube as a rectifier for radio and audio frequency measurements will be taken up in a later lesson. Crystal detectors may be used in series with a micro or milliampere meter, but as the crystal is a device difficult to maintain in unvarying operation, it can only

*It is possible to build a meter of this type for use with frequencies up to 1,000 c.p.s. However, it is not done in practice.

be used as a current indicator rather than a current measuring device. For some time the copper oxide rectifier has been used in A battery chargers, and as a means of changing A.C. to D.C. for feeding the electromagnets in dynamic loudspeakers. Recently a small oxide rectifier has been designed which will rectify current of 1 or 2 milliamperes and arranged in bridge formation as shown

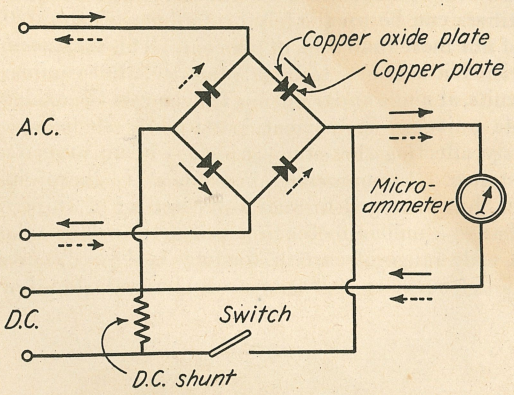


Fig. 16a

in Fig. 16a, they provide an efficient rectifying system for use with sensitive D.C. meters.

Note the special arrangement of four rectifiers in a diagonal arrangement, intended to give full-wave rectification. If you will follow through the solid and dotted arrows, it will be clear that the current will always flow through the

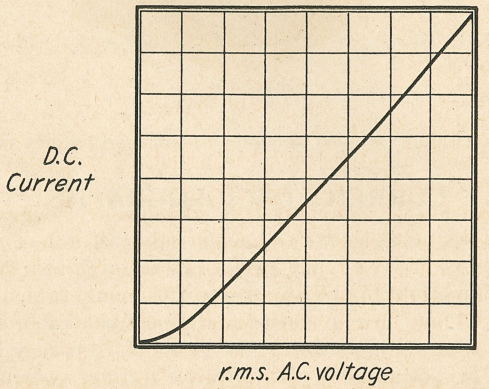


Fig. 16b

microammeter in one direction. A sensitive microammeter is essential as the rectified current will be considerably less than the r.m.s. value of A.C. current. One manufacturer uses a throw-over switch which allows the same microammeter to be used on D.C. measurements. A shunt as shown in Fig. 16a or a series resistance in the D.C. terminal leads is necessary to compensate for the current loss in the rectifier, if the same calibration scale is to be used.

Fig. 16b is a typical curve of rectified current, plotted against D.C. current. It is practically a straight line except at small A.C. currents, which results in a bunched-up reading near zero on the scale. This will tend to throw the lower readings for D.C. off, so the service man must be careful to use a shunt for D.C. which will bring the reading at least 15 per cent up on the scale and very little use of the lower readings should be made.

Oxide rectifiers can be used safely on frequencies from 20 to 10,000 c.p.s. with an error of not more than 5 to 10 per cent. This may seem too much error, but from experience it is known to be satisfactory. For commercial use, in A.C. power pack circuits, at audio and telephone frequencies, the oxide rectifier ammeter is a remarkable universal instrument, particularly so because it will operate without seriously affecting the circuit which is being measured because of its negligible resistance. A commercial instrument is shown in Fig. 16c, with built-in rectifier, but arranged to read volts instead of amperes. The method employed to change a milliammeter to a voltmeter will be taken up in another text. Where a wide range of current readings is desired, current transformers with no distortion, from 20 to 10,000 c.p.s., can be used (step-down transformers).

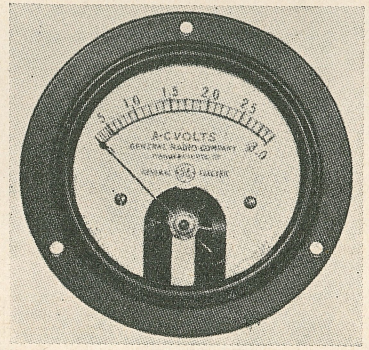


Fig. 16c

The transformers cannot be used at their cut-off frequencies without considerable error.

CURRENT OSCILLOGRAPHS

In our entire discussion so far we have assumed that the current, if D.C., is constant in value, and, if A.C., has a pure sine wave form. Where they differ from this, an average D.C. or an equivalent A.C. r.m.s. value only can be read on the meters. These are average conditions, but often a knowledge of the true state of affairs is important. For example, tests may be conducted on A.C. hum, let us say, from a 60 cycle full wave rectifier system. The hum will be 120 cycles, but there are harmonics present. An oscillograph would show that they were present. In a sound studio, you might want to know if the audio apparatus was working without using a speaker. An oscillograph would show an exact electrical picture of the audio current. Oscillographs enable one to "see" the current wave form.

Fig. 17 is an elementary sketch of the moving element. There are two phosphor-bronze ribbon wires (W), extremely thin and narrow, firmly stretched by spring across two supporting bridges b and b'. The tension on the wire fila-

ments may be increased or decreased by means of the thumb nut T. This system is set between the poles of a strong electromagnet, and it is important for purposes of measurement that the magnetic lines of force be uniform from pole

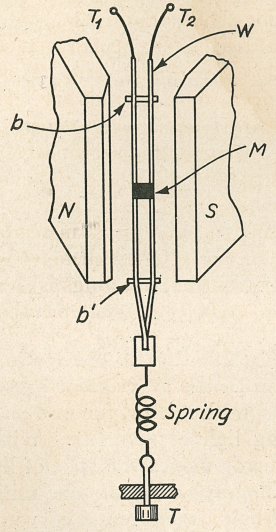


Fig. 17

face to pole face. For portable oscillographs, powerful permanent magnets may be used.

Current is led into one wire and out through the other, resulting in a weak magnetic field. This field is at right angles to the strong electromagnetic field

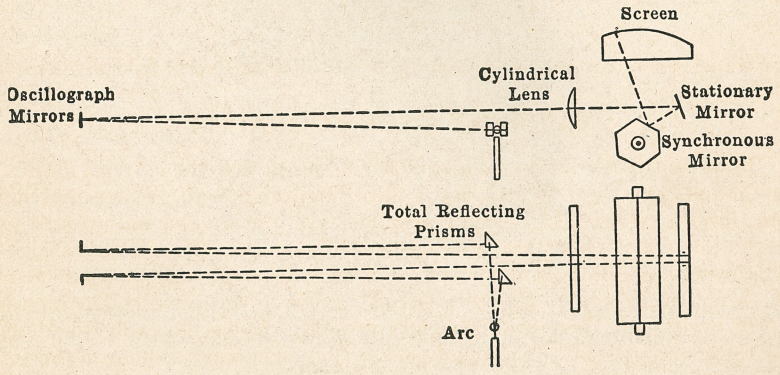


Fig. 18

and naturally both fields tend to line up, resulting in a twisting of the wires. A very small, thin mirror is cemented to the center where the twist is greatest. The greater the current, the greater the angle of twist. They are directly proportional; that is, the angle for 40 mils. will be twice that for 20 mils.; and four times

larger for 80 mils. When the current reverses, the twist is in the opposite direction.

A very intense beam of light, frequently supplied by a direct current arc, is directed to the small oscillograph mirror M. The beam of light, after being reflected from the oscillograph mirror (see Fig. 18), passes through a long cylindrical lens which focuses the spot of light on a tilted stationary mirror, from which it is reflected to a syncronous mirror and then thrown onto a ground glass screen. When an alternating audio current is caused to flow through the oscil-

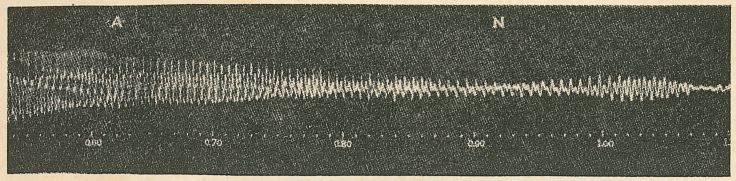


FIG. 19

lograph, the mirror twists back and forth, exactly in step with every variation of the current. Therefore, with the syncronous mirror stationary, the reflected spot of light from the oscillograph mirror, focused on the screen, moves up and down, appearing like a long lighted filament. With the oscillograph mirror stationary, the revolving mirror moves the spot of light at right angles to the motion given it by the oscillograph. As the one mirror rotates, and the other mirror vibrates, the spot of light traces out a curve on the ground glass. The result is a wave-like form which can be seen by the human eye.

For permanent recording, the stationary and revolving mirrors are dis-

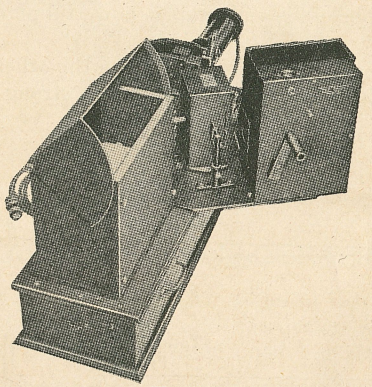


FIG. 20

pensed with and the spot of light is allowed to fall directly on a constantly forward moving photographic film. When the film is developed a wave form appears on it as in Fig. 19 which now may be analyzed.

The oscillograph element is like the voice coil of a dynamic speaker—a vibrating system. It is essential that it have no resonance peaks of its own; otherwise the wave form will not be correct. Quite often, the element is immersed in oil to prevent a natural period of vibration. If the revolving mirror is connected to a synchronous motor, which itself is operated by the current which is being studied by the oscillograph, and if the current is periodic—that is,

repeats itself—the wave form on the screen will appear at a standstill and it may be traced on thin paper. Fig. 20 shows a typical modern commercial oscillograph.

In some oscillographs, two vibration galvanometers (the technical name when the moving element is used) are employed. One is used to analyze the unknown current and the other is fed with a sine wave current of constant frequency, allowing the other curve to be calibrated for time. The measuring galvanometer can be calibrated for amplitude just as any galvanometer—that is, by putting various values of current through and measuring the deflection in millimeters—in which case, $I_g = K \times D$.

In the oscillograph shown in Fig. 20, a tungsten wire, .0004 inch in diameter is used, having a resistance of 45 ohms. At 500 cycles, and with the galvanometer out of resonance with the signal, .06 ampere will give a deflection on the ground glass of 1 millimeter. If the galvanometer is tuned to 500 cycles by adjusting the thumb screw T, .0005 ampere will give a deflection of 1 millimeter. Where large currents are to be measured, a step-down transformer is used.

TEST QUESTIONS

Number Your Answer Sheet 28FR and Add Your *Student Number*.

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way, we shall be able to work together much more closely, you'll get more out of your Course, and the best possible lesson service.

1. What is meant by the meter constant of a D.C. milliammeter?
2. Explain briefly the principle of the thermocouple ammeter.
3. Draw a diagram of a combination A.C. and D.C. milliammeter using a copper oxide bridge rectifier.
4. In measuring the plate current in a resistance coupled amplifier stage, is it essential that a milliammeter having a very low resistance be used? Explain.
5. How can a milliammeter be used to measure currents of several amperes?
6. If you have a solenoid with a soft iron plunger in it connected in such a way that when current flows the plunger will be drawn into the solenoid, will reversing the direction of current flow cause the plunger to be forced out of the solenoid? Explain.
7. How is a calibration curve of a milliammeter made?
8. When are oscillographs used?
9. What two methods of damping are used in meters?
10. Would you use a hot wire or a thermocouple ammeter for measuring weak R.F. currents?